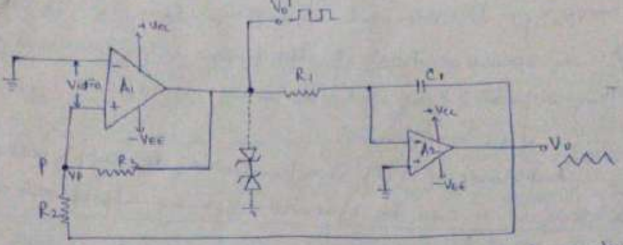
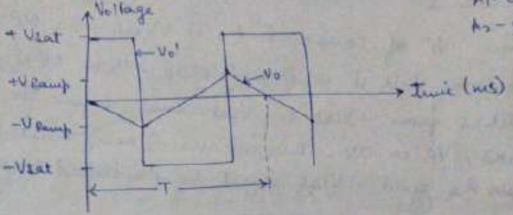
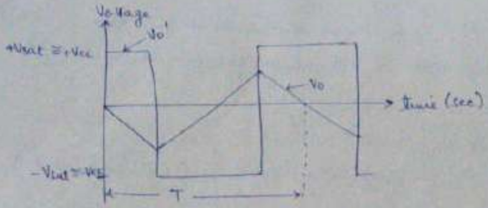


A1 - comparator
A2 - integrator



A_1 compares the voltage at P with the inverting I/P that is 0V. When V_P goes slightly below 0V, the O/P of A_1 is at the negative saturation & when V_P goes slightly above 0V, O/P of A_1 goes to +ive saturation level.

If A_1 is at +ive sat, $+V_{sat}$ ($\cong +V_{CC}$); I/P to A_2 is $+V_{sat}$, ∴ the O/P of A_2 will be a negative going Ramp. Thus one end of voltage divider R_2-R_3 is the positive saturation voltage $+V_{sat}$ of A_1 and the other is the negative going Ramp of A_2. When this Ramp attains a value of $-V_{Ramp}$, point P is slightly below 0V. Hence O/P of A_1 switches from +ive saturation to -ive saturation $-V_{sat}$ ($\cong -V_{EE}$). ∴ O/P of A_2 will now begin



For o/p of A_2 to be triangular, $5R_3C_2 > T/2$

Generally $R_3C_2 = T$

For stable Δ o/p, shunt C_2 with R_4 ($= 10R_3$) and connect an offset compensating N/w at the noninverting i/p of A_2.

Freq. of Δ wave generator is limited by the slew rate of the op-amp (as in any oscillator). ∴ high slew rate op-amp like LM301 is used for generating higher freqs.

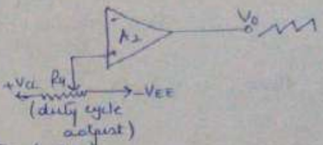
Another Δ wave generator which uses lesser no. of components can also be used. It consists of a comparator and an integrator

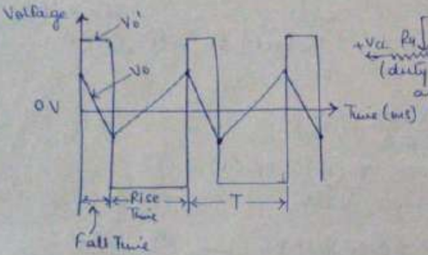
Sawtooth Wave Generator

In Δ wave, rise time = fall time

Sawtooth wave has unequal rise & fall times.

The ckt. is same as ~~sum~~ Δ wave generator except that the noninverting terminal of A_2 is connected to a variable dc voltage (by using potentiometer & connecting it to $+V_{cc}$ and $-V_{EE}$)





Depending on the R_4 setting, a certain dc level is inserted in the o/p of A_2. This would mean that o/p of A_2 will be a Δ wave riding on some dc level that is a function of the R_4 setting. The duty cycle of the square wave will be determined by the polarity and amplitude of this dc level. A duty cycle < 50% causes o/p of A_2 to be a sawtooth. Wiper of R_4 in the center gives o/p of A_2 as a Δ wave. When wiper of R_4 moves towards $-V_{EE}$, Rise time > Fall Time. If wiper moves towards $+V_{cc}$, Fall time > Rise Time

Amplitude of sawtooth wave is independent of R_4 setting to go positively. This continues till A_2 reaches $+V_{Ramp}$. At this pt. P is slightly above 0V, ∴ o/p of A_1 is switched back to the positive saturation level $+V_{sat}$. This repeats & we get the above waveform.

$$f_{\sqcap\sqcup} = f_{\Delta\sim}$$

Amplitude of ⊓⊔ is a function of dc supply voltages; or a desired " can be obtained by using appropriate zeners at the o/p of A_1.

* When o/p of comparator A_1 is $+V_{sat}$, the o/p of A_2 decreases till it reaches $-V_{Ramp}$. Here o/p of A_1 switches from $+V_{sat}$ to $-V_{sat}$. Just before the switching occurs, V_P is 0V. This means $-V_{Ramp}$ must be developed across R_2 and $+V_{sat}$ must be developed across R_3.

$$\therefore \quad \frac{-V_{Ramp}}{R_2} = -\frac{+V_{sat}}{R_3}$$

$$\text{or} \quad -V_{Ramp} = -\frac{R_2}{R_3}(+V_{sat}) \quad \text{—} (1)$$

Similarly, $+V_{Ramp}$, the o/p of A_2 at which o/p of A_1 switches from $-V_{sat}$ to $+V_{sat}$ is,

$$+V_{Ramp} = \frac{-R_2}{R_3}(-V_{sat}) \quad \text{—} (2)$$

∴ peak-to-peak o/p amplitude of Δ o/p is

$$V_o(p\text{-}p) = +V_{Ramp} - (-V_{Ramp})$$

$$\boxed{V_o(p\text{-}p) = 2\frac{R_2}{R_3}(V_{sat})} \quad \text{—} (3)$$

Q) Design the square wave osc. so that $f_0 = 1KHz$. Op-amp used is 741 with dc supply voltages $= \pm 15V$.

Ans) Use $R_2 = 1.16 R_1$

let $R_1 = 10K\Omega$

Then, $R_2 = (1.16)(10) = 11.6K\Omega$ (Use $R_2 = 20K\Omega$ pot)

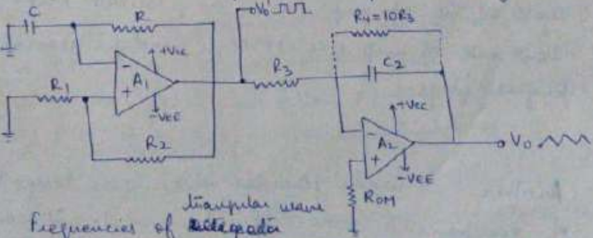
Next, choose $C = 0.05\,\mu f$, $f_0 = \frac{1}{2RC}$

$$R = \frac{1}{2 f_0 C} = \frac{1}{2\times10^3 \times 0.05\times10^{-6}} = 10K\Omega$$

Thus $R_1 = 10K\Omega$, $R_2 = 11.6K\Omega$, $R = 10K\Omega$, $C = 0.05\,\mu f$.

Triangular Wave Generator

(I) Connect an integrator to a square wave generator.



Frequencies of triangular wave & square wave generators is the same. For fixed R_1, R_2, C the freq. of square & triangular wave depends on $\underline{\underline{R}}$

$$f_0 = \frac{1}{2RC\ln[(2R_1+R_2/R_2)]}$$

Although amplitude of square wave is constant ($\pm V_{sat}$), the amp. of Δ wave decreases with ↑ in freq. & viceversa the o/p of the op-amp is forced to switch to a negative saturation, $-V_{sat}$. When V_0 is at $-V_{sat}$, V_1 across R_1 is also negative, since

$$V_1 = \frac{R_1}{R_1+R_2}(-V_{sat})$$

Thus $V_{id} = V_1 - V_2$ is negative which holds the V_0 at $-V_{sat}$. o/p remains at $-V_{sat}$ till capacitor C discharges and then recharges to a -ive voltage slightly higher than $-V_1$.

As soon as capacitors voltage V_2 becomes more negative than $-V_1$, V_{id} becomes positive.

$$\left\{ V_{id} = [V_1] - [V_2] = V_1 - (-V_2) = V_1 + V_2 = +\text{ive} \right\}$$

and hence drives the o/p of the op-amp back to its +ive saturation $+V_{sat}$. This completes one cycle.

With o/p at $+V_{sat}$; V_1 (at noninverting i/p) $= \frac{R_1}{R_1+R_2}(+V_{sat})$

Time period of the o/p waveform is,

$$T = 2RC \ln\left(\frac{2R_1+R_2}{R_2}\right)$$

$$\text{or } f_0 = \frac{1}{2RC \ln[(2R_1+R_2)/R_2]}$$

If ckt. is operated at higher freqs., ac. o/p becomes Triangular

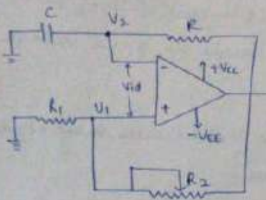
$\Rightarrow f_0 = \text{func}\left[RC \text{ time constant}, R_1 \& R_2\right]$.

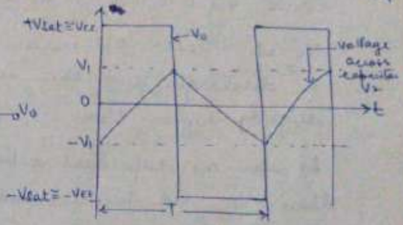
$$\boxed{\text{if, } R_2 = 1.16 R_1, \quad \text{Then } f_0 = \frac{1}{2RC}}$$

Smaller the time constant RC, higher is the o/p freq. f_0

⑥

Square Wave Generator :- Square wave o/ps are generated when the op-amp is forced to operate in the saturated region. o/p is forced to swing repeatedly between the saturation $+V_{sat}$ ($\cong V_{cc}$) and $-V_{sat}$ ($\cong -V_{EE}$). It is also called a free running or astable Multivibrator. o/p is $+V_{sat}$ or $-V_{sat}$ depending on whether V_{id} is +ive or -ive reg.





$$|V_1| = \frac{R_1}{R_1+R_2}|V_{sat}|$$

$$f_o = \frac{1}{T} = \frac{1}{2RC} \text{ if } R_2 = 1.16R_1$$

Assume that voltage across cap. = 0V at the instant the dc supply voltages $+V_{cc}$ & $-V_{EE}$ are applied
⇒ Voltage at the Inverting i/p terminal = 0 initially.
At the same time, V_1 at the noninverting terminal is a very small finite value which is a function of o/p offset voltage V_{OOT} and values of R_1 and R_2. Thus $V_{id} = V_1$ at noninverting terminal. Thus V_1 starts to drive the op-amp into saturation. e.g if V_{OOT} is positive, V_1 is also +ive. Initially C acts as a short ckt, gain of the op-amp (A) is very large; hence V_1 drives o/p to $+V_{sat}$. With the o/p voltage of the op-amp at $+V_{sat}$, C starts charging towards $+V_{sat}$ through R. As soon as V_2 across C is slightly more positive than V_1,

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$

so amplitude of Δ wave decreases with an increase in R_3.

Time it takes for the o/p waveform to swing from $-V_{Ramp}$ to $+V_{Ramp}$ = 1/2 the time period $T/2$.

We know that the integrator o/p is,

$$V_o = \frac{-1}{RC}\int_0^t V_{in} \cdot dt + C$$

Here $V_i = -V_{sat}$
$V_o = V_o(p-p)$

Here, $$V_o(p-p) = \frac{-1}{R_1C_1}\int_0^{T/2}(-V_{sat})\,dt \quad — (4) \quad \& \ C = 0$$

$$= \left(\frac{V_{sat}}{R_1C_1}\right)\left(\frac{T}{2}\right)$$

Hence $$\frac{T}{2} = \frac{V_o(p-p)}{V_{sat}}(R_1C_1)$$

$$T = 2R_1C_1\frac{V_o(p-p)}{V_{sat}} \quad — (5)$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$

Substitute the value of $V_o(p-p)$ in (5) from (3),

$$T = \frac{2R_1C_1}{V_{sat}}\left(2\frac{R_2}{R_3}V_{sat}\right)$$

$$\boxed{T = \frac{4R_1C_1R_2}{R_3}} \quad — (6)$$

Freq. of oscillation, $f_o = \frac{R_3}{4R_1C_1R_2}$

$f_o \uparrow$ with $\uparrow$ in R_3

Astable Applications :-

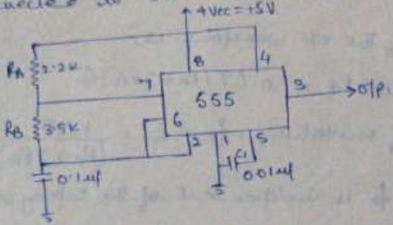
(1) Square wave osc. (2) free Running Ramp Generator

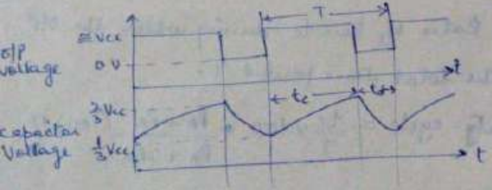
Astable Multivibrator → Free Running operation (5)

→ rectangular wave generating ckt.

→ does not require external trigger to change the state of the o/p.

→ Time during which the o/p is H or L is determined by resistors and a capacitor, which are externally connected to 555 timer.





Initially, when o/p is H, C starts charging towards Vcc through RA and RB.

As voltage across C, $V_c = 2/3 V_{cc}$, comparator 1 triggers the FF, and o/p switches low. Now C starts discharging through R_B and Q_1. When the $V_c = \frac{1}{3} V_{cc}$, comparator 2's o/p triggers the FF, & o/p goes HIGH. Then the cycle repeats.

C is repeatedly charged & discharged between $\frac{2}{3} V_{cc}$ and $1/3$ Vcc resp.

Time during which C charges $\frac{1}{3}V_{cc}$ to $\frac{2}{3}V_{cc}$ = time the o/p is high and is given by,

$$t_c = 0.69(R_A + R_B)C$$

Time during which C discharges from $\frac{2}{3}V_{cc}$ to $\frac{1}{3}V_{cc}$ = time the o/p is low and is given by,

$$t_d = 0.69(R_B)C$$

Total period of the o/p waveform is,

$$T = t_c + t_d = 0.69(R_A + 2R_B)C$$

So, freq. of oscillation, $f_0 = \frac{1}{T} = \frac{1.45}{(R_A + 2R_B)C}$ — (A)

(A) shows that f_0 is independent of the supply voltage V_{cc}.

Duty cycle = Ratio of time t_c during which the o/p is high to the total time period T.

$$\% \text{ Duty cycle} = \frac{t_c}{T} \times 100 = \frac{R_A + R_B}{R_A + 2R_B}(100)\,\%.$$